Measurement of Excited Charm and Charm-Strange mesons at HERA

Yehuda Eisenberg
Weizmann Institute of Science
Israel

on behalf of the
ZEUS Collaboration
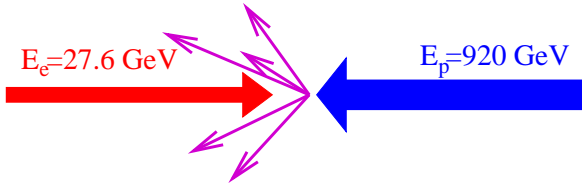
O U T L I N E

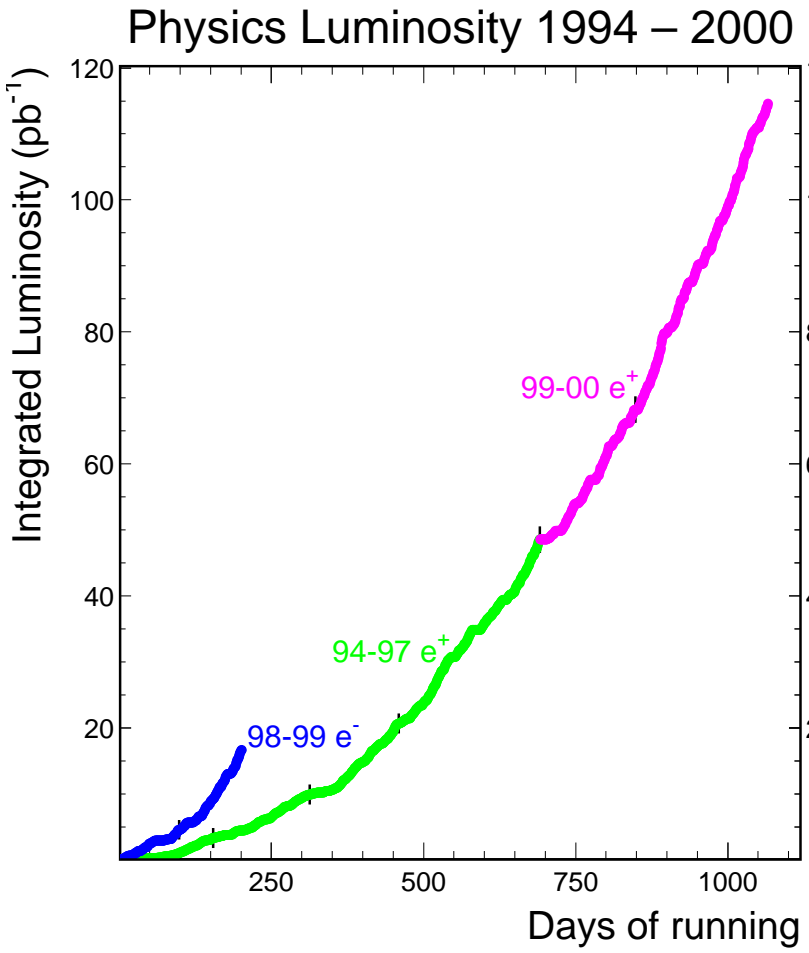- **Introduction**
- **Excited Charm Mesons**
- **Production of** $D_1^0 \to D^{*\pm}\pi^{\mp}, D_2^{*0} \to D^{*\pm}\pi^{\mp}, D^{\pm}\pi^{\mp}$
- **Production of** $D_{s1}^{\pm} \to D^{*\pm}K_s^0, D^{*0}K^{\pm}$
- **Search For** $D^{*'\pm} \to D^{*\pm}\pi\pi$ **at** $\sim 2.64 GeV$
- **Summary**

E_e=27.6 GeV $\quad$ E_p=920 GeV

Physics Luminosity 1994 − 2000

99-00 e$^+$

94-97 e$^+$

98-99 e$^-$

Integrated Luminosity (pb^{-1})

Days of running

ZEUS Luminosity : $126\,\mathrm{pb}^{-1}$

	HERA I 1992-2000	**HERA II** 2003-2007
$\sqrt{s}$	$318\,(\mathbf{300})$	$318\,\mathbf{GeV}$
$\mathcal{L}$	$1.5\cdot 10^{31}$	$7\cdot 10^{31}\,cm^{-2}\,s^{-1}$
$\mathcal{L}_{int}$	~ 0.12	$\sim 0.4\,fb^{-1}$

$$e(k) + p(P) \to e(k') + X \qquad s = (P+k)^2$$

$$Q^2 = -q^2 = -(k-k')^2$$

Photoproduction $\qquad Q^2 \simeq 0\,GeV^2$

DIS $\qquad Q^2 > 1,5\,GeV^2$
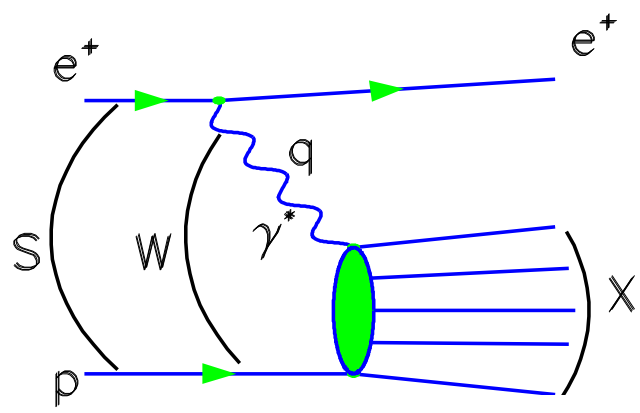
$$W^2 = (P+q)^2$$

$$y = \frac{qP}{kP} \cong \frac{W^2+Q^2}{s}$$
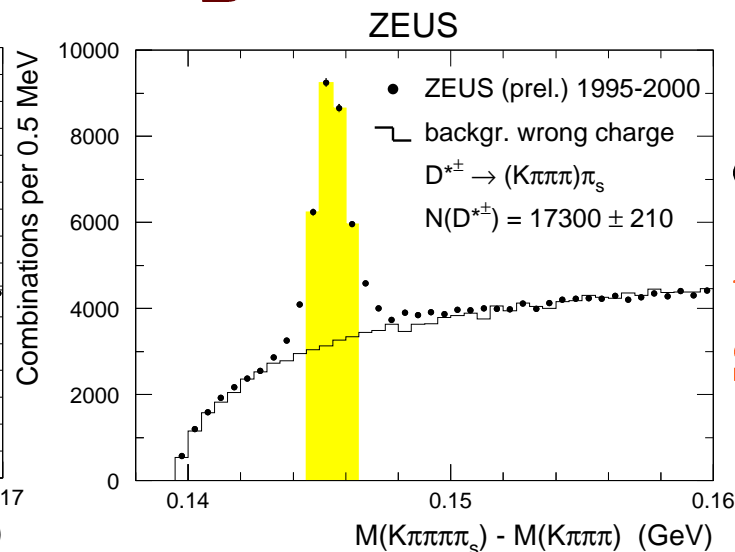
$$x = \frac{Q^2}{2qP} \cong \frac{Q^2}{sy}$$

$\mathcal{L}_{int}$: 126pb^{-1} 1995-2000   Full phase space; DIS $+ \gamma p$ events

Decays : $D^{*+} \to D^0 \pi^+, D^0 \to K^- \pi^+, K^- \pi^+ \pi^+ \pi^- + cc$
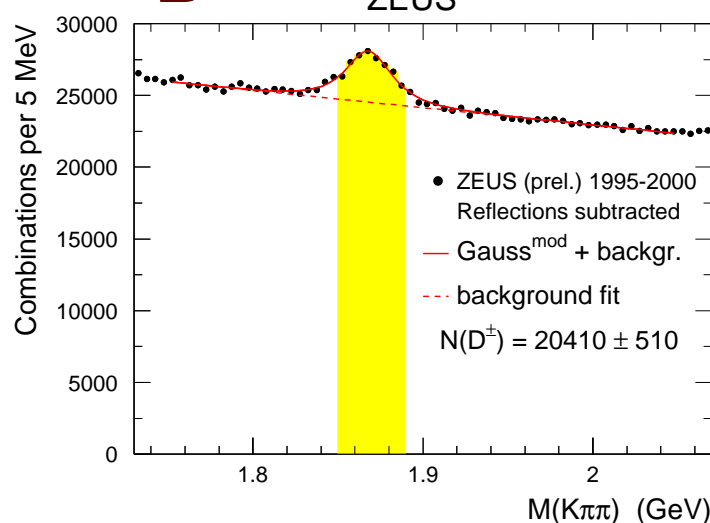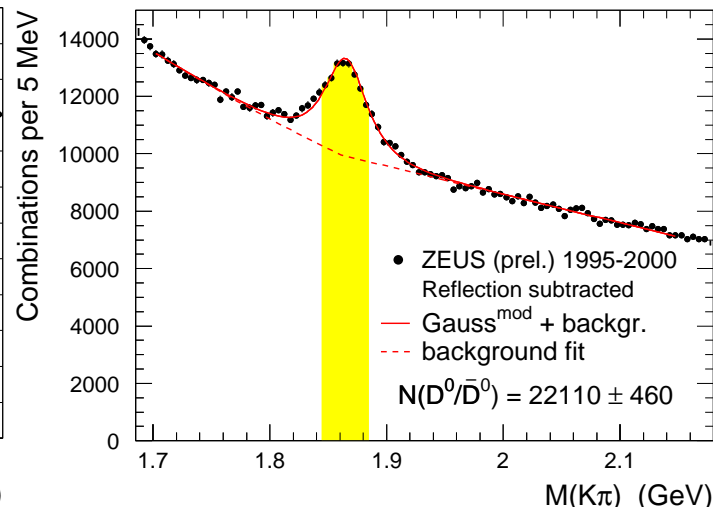
$D^{*\pm}$
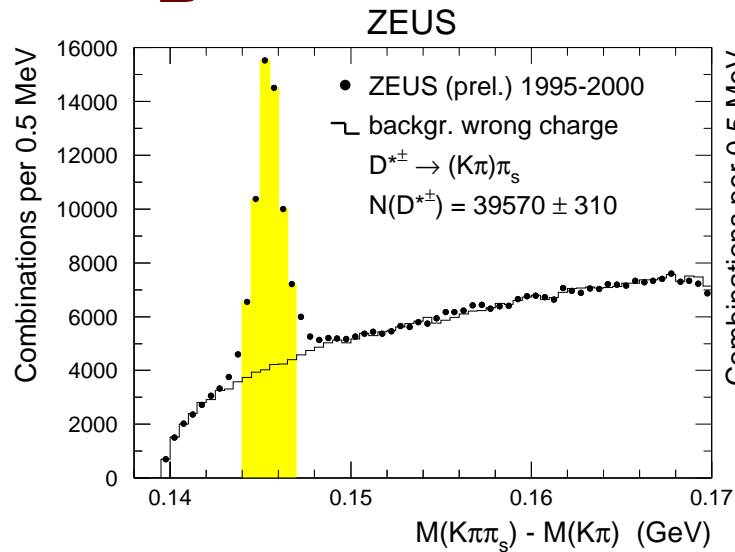
$D^{*\pm}$

Ground states : Eur.Phys.J.C 44 (2005)35

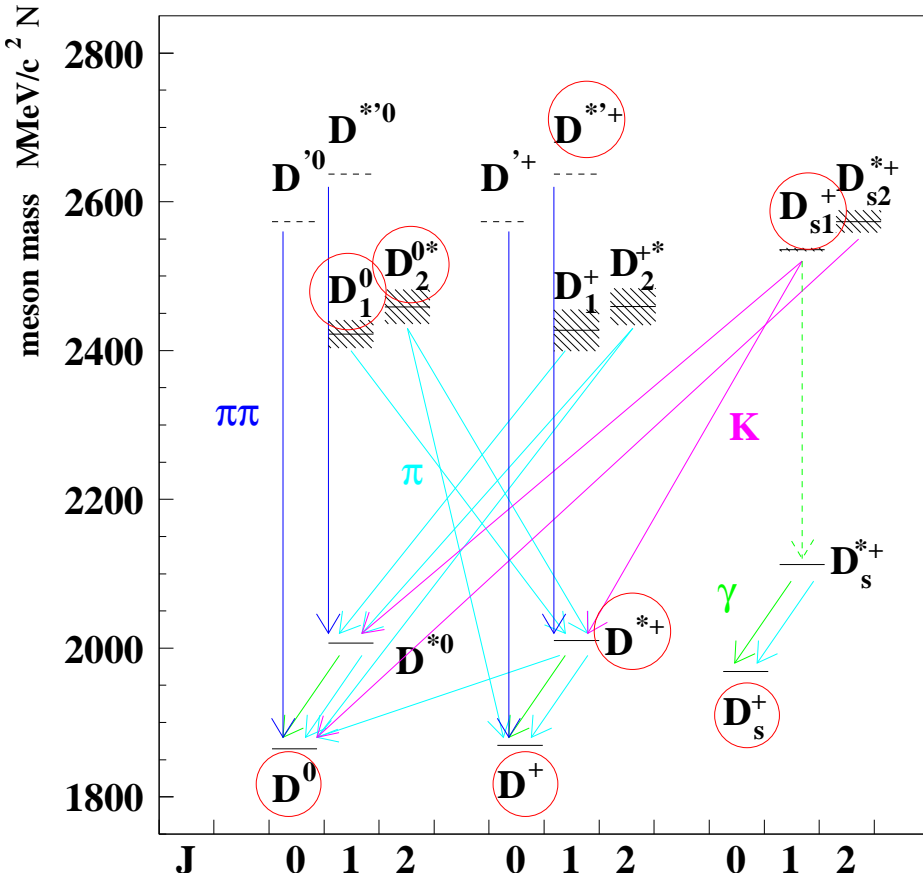$N(D^{*\pm})$ from

Signal-Wrong Charge Bkgd

$D^{\pm}$

$D^0 (\overline{D^0})$

$N(D^0), N(D^{\pm})$ from fit to

$Gauss^{mod}$ + Bkgd

$Gauss^{mod} \sim exp(-0.5x^{1+\frac{1}{(1+0.5x)}})$

D^0 NOT from $D^{*\pm}$ decays

meson mass N MeV/c^2

2800
2600
2400
2200
2000
1800

$\pi\pi$

π

K

γ

D^{*0} $D^{'0}$ $D^{*'0}$

D^0_1 D^{0*}_2

$D^{'+}$ $D^{*'+}$

D^+_1 D^{+*}_2

D^+_{s1} D^{*+}_{s2}

D^{*+}_s

D^{*0}

D^{*+}

D^+_s

D^0

D^+

J   0 1 2   0 1 2   0 1 2

Study : $D^0_1, D^{*0}_2 \to D^{*\pm}\pi^{\mp}, D^{*0}_2 \to D^{\pm}\pi^{\mp}$

$D^{\pm}_{s1} \to D^{*\pm}K^0_s, D^{*0}K^{\pm}$

Aim: Measure Excited Charm Rates:

$f(c \to D^0_1), f(c \to D^{*0}_2), f(c \to D^{\pm}_{s1})$

And Branching Fractions:

$\dfrac{B(D^{*0}_2 \to D^+\pi^-)}{B(D^{*0}_2 \to D^{*+}\pi^-)}, \quad \dfrac{B(D^+_{s1} \to D^{*0}K^+)}{B(D^+_{s1} \to D^{*+}K^0)}$

Using $\quad f(c \to D^{*\pm}), f(c \to D^{\pm}), f(c \to D^0)$

And Excited Charm Rates will yield Ratios:

$R(\dfrac{D^0_1 \to D^{*+}\pi^-}{D^{*+}}), R(\dfrac{D^{*0}_2 \to D^{*+}\pi^-}{D^{*+}}), R(\dfrac{D^{*0}_2 \to D^+\pi^-}{D^+}), R(\dfrac{D^+_{s1} \to D^{*+}K^0}{D^{*+}}), R(\dfrac{D^+_{s1} \to D^{*0}K^+}{D^0})$

In Heavy Quark Effective Theory(HQET): The Helicity parameter,H is

$\dfrac{dN}{dcos\theta} \sim 1 + Hcos^2\alpha, \ H = 3(-1) \ $ for $J^P = 1^+(2^+) \ $ from $j = 3/2 \ $ doublet

α : Angle in $D^{*\pm}$ rest frame between extra $\pi^{\mp}(K^0_s) \ $ and $\pi_s \ (D^{*\pm} \to D^0\pi_s)$

Aim : Compared to e^+e^- Experiments-look for Charm Decay Universality

ZEUS(Prelim.) Excited Charm Mesons

Combine charged $D^*(D)$ with π of opposite charge, π_e

ZEUS

- ZEUS (prel.) 1995-2000
- Backgr. wrong charge

$N(D_1^0/\bar{D}_1^0) = 3030 \pm 340$

$N(D_2^{0*}/\bar{D}_2^{0*}) = 880 \pm 170$

$M(D^{*\pm}\pi) = \Delta M^{ext} + M(D^{*+})_{PDG}$ (GeV)

— simultaneous fit
--- background fit

$N(D_2^{0*}/\bar{D}_2^{0*}) = 680 \pm 160$

$M(D^{\pm}\pi) = \Delta M^{ext} + M(D^+)_{PDG}$ (GeV)
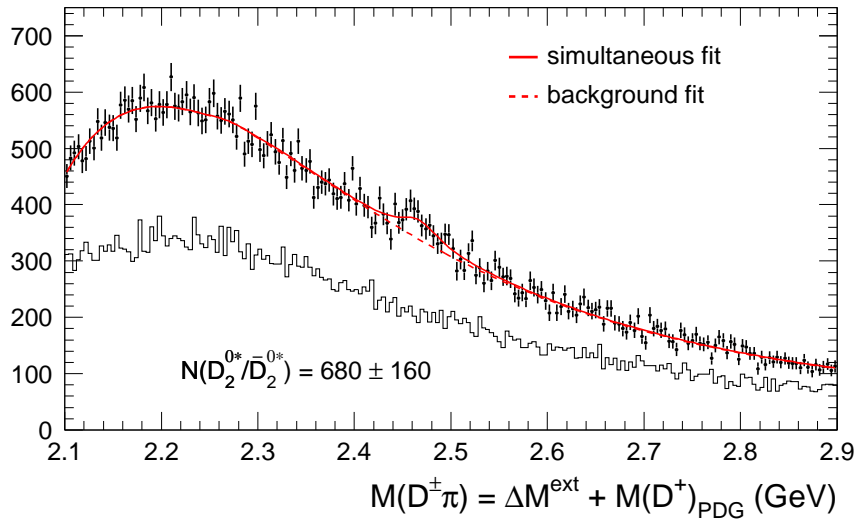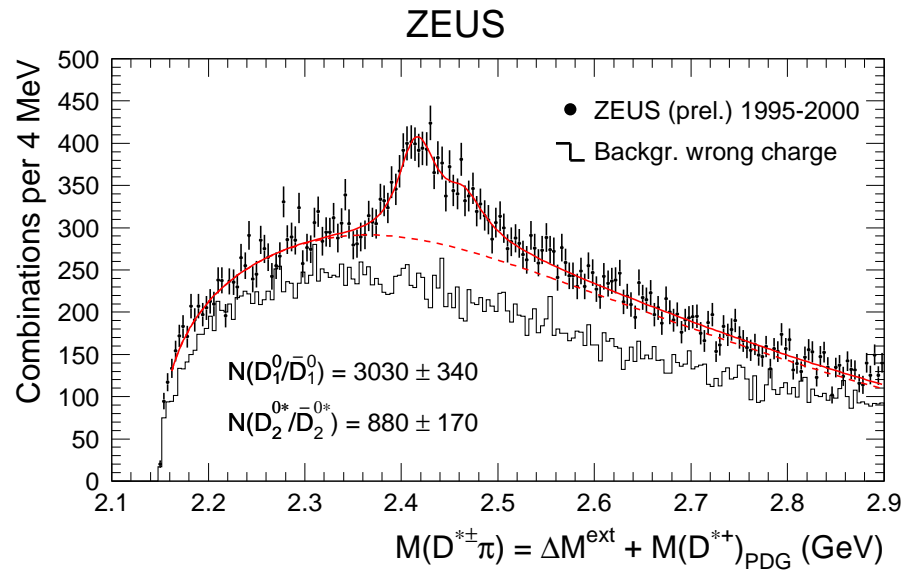
$\Delta M^{ext} = M(K\pi\pi_s\pi_e) - M(K\pi\pi_s)$

$p_t(D^{*\pm}) > 1.35 GeV,\ |\eta(D^{*\pm})| < 1.6$

$\Delta M^{ext} = M(K\pi\pi\pi_s\pi_e) - M(K\pi\pi\pi_s)$

Select: $p_t(D^{*\pm}) > 2.80 GeV,\ |\eta(D^{*\pm})| < 1.6$

In Plots : sum of $K\pi$ and $K\pi\pi\pi$ D^0 decays

15 parameter fit $\chi^2/\mathrm{df}, = 0.99$

Difficult to separate D_1^0 from D_2^{*0}

$\Delta M^{ext} = M(K\pi\pi\pi_e) - M(K\pi\pi)$

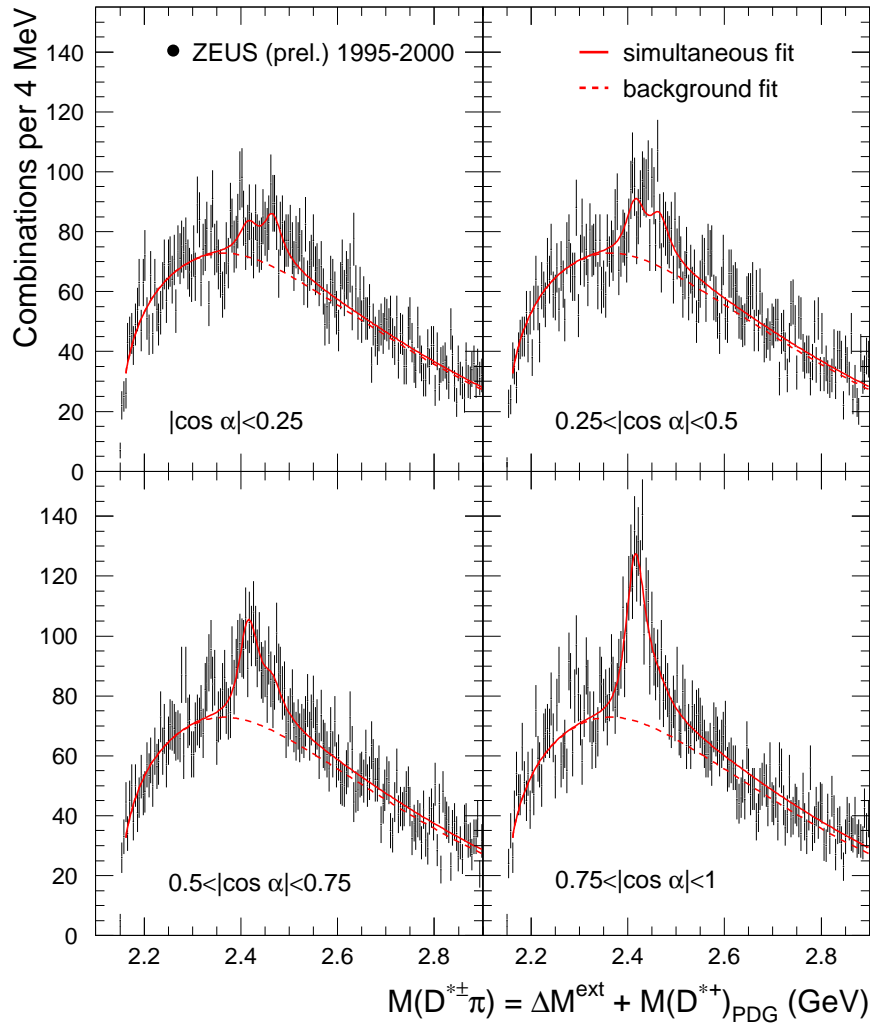Cuts : $p_t(D^{\pm}) > 2.80 GeV,\ |\eta(D^{\pm})| < 1.6$

By Spin-Parity: $D^{\pm}\pi^{\mp}$ is only from D_2^{*0} decays

ZEUS(Prelim.) Excited Charm Mesons

Simultaneous fit to 4 helicity $M(D^{*\pm}\pi^{\mp})$ Regions and $M(D^{\pm}\pi^{\mp})$ histogram

χ^2 (15 param.)fit to variable width relativistic Breit-Wigner function convoluted with experimental resolution + background function

ZEUS

- ZEUS (prel.) 1995-2000
- — simultaneous fit
- - - background fit

Combinations per 4 MeV

140, 120, 100, 80, 60, 40, 20, 0

$|\cos\alpha|<0.25$

$0.25<|\cos\alpha|<0.5$

$0.5<|\cos\alpha|<0.75$

$0.75<|\cos\alpha|<1$

$M(D^{*\pm}\pi) = \Delta M^{ext} + M(D^{*+})_{PDG}$ (GeV)

In high $\cos(\alpha)$ bin almost all $D_1^0 \sim 1 + 3cos^2\alpha$

$M(D_1^0) = 2419.8 \pm 2.0^{+0.8}_{-1.0} MeV$ (Prel.)

$M(D_2^{*0}) = 2468.4 \pm 3.6^{+1.1}_{-1.3} MeV$ (Prel.)

$\Gamma(D_1^0) = 51.6 \pm 7.0^{+1.9}_{-4.1} MeV (20.4 \pm 1.7 PDG06)$

$\Gamma(D_2^{*0}) = 43 MeV$ (taken fixed from PDG06)

$H(D_1^0) = 5.9^{+3.0}_{-1.7}(stat)^{+1.9}_{-0.8}(syst)$

$H(D_2^{*0}) = -1$ Fixed in Fit ($J^P = 2^+$ pure state)

$R(\frac{D_1^0 \to D^{*+}\pi^-}{D^{*+}}), R(\frac{D_2^{*0} \to D^{*+}\pi^-}{D^{*+}}), R(\frac{D_2^{*0} \to D^+\pi^-}{D^+})$

Extrapolated to full kinematic phase space yields:

$\frac{B(D_2^{*0} \to D^+\pi^-)}{B(D_2^{*0} \to D^{*+}\pi^-)} = 2.7 \pm 0.8(stat.) \pm 0.6(syst.) \pm 0.1(ext.)$ 2.3 ± 0.6 (PDG06)

Excited Charm Strange Mesons : $D_{s1}^{\pm} \to D^{*\pm}K_s^0, D^{*0}K^{\pm}$

ZEUS (prel.) 1995-2000
K_s^0 candidates in events with a $D^{*\pm}$ candidate

Combinations per 1 MeV

$M(\pi^+\pi^-)$ (GeV)
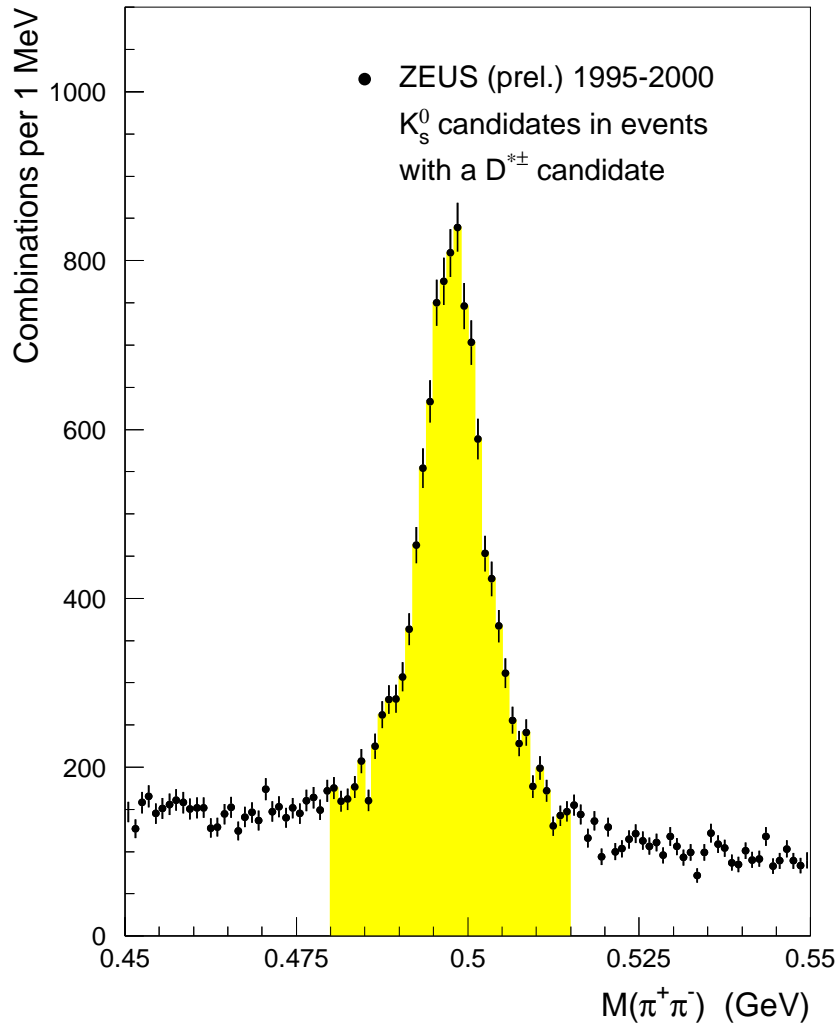
Selection of K_s^0 candidates :

For both its pions $p_t(\pi) > 0.15 GeV$

Fit to $Gauss^{mod}$ + Linear Bkgd yielded

$M(K_s^0) = 497.8 \pm 0.1$, $\sigma(K_s^0) = 4.1 \pm 0.1$ Mev

In selected region : $0.480 < M(K_s^0) < 0.515 GeV$
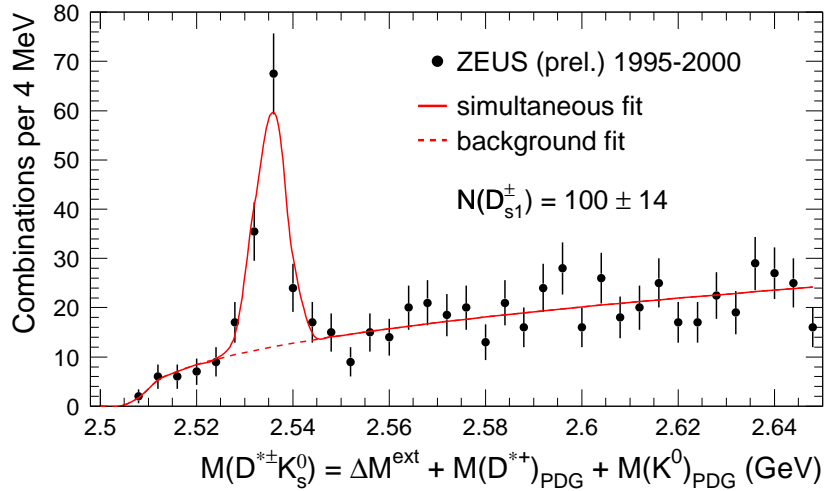
8540 ± 120 events were found

$\frac{dE}{dx}$ selection was used for $K^{\pm}, \pi$

ZEUS(Prelim.) Excited Charm Strange Mesons

Simultaneous fit of $M(D^{*\pm}K_s^0)$, $M(D^0K^\pm)$ and $cos(\alpha)$ distributions

Gaussian ($Gauss^{mod}$ for $M(D^0K^\pm)$)+ background unbinned liklihood fit

ZEUS

- ZEUS (prel.) 1995-2000
— simultaneous fit
- - - background fit

$N(D_{s1}^\pm) = 100 \pm 14$

$M(D^{*\pm}K_S^0) = \Delta M^{ext} + M(D^{*+})_{PDG} + M(K^0)_{PDG}$ (GeV)

$N(D_{s1}^\pm) = 135 \pm 27$

$M(D^0K^+) = \Delta M^{ext} + M(D^0)_{PDG}$ (GeV)

$\Delta M^{ext} = M(K\pi\pi_s\pi^+\pi^-) - M(K\pi\pi_s)$

$p_t(D^{*\pm}) > 1.35 GeV, \quad |\eta(D^{*\pm})| < 1.6$

$\Delta M^{ext} = M(K\pi\pi\pi_s\pi^+\pi^-) - M(K\pi\pi\pi_s)$

$p_t(D^{*\pm}) > 2.80 GeV, \quad |\eta(D^{*\pm})| < 1.6$

Plot contains sum of $K\pi$ and $K\pi\pi\pi$ $D^{*\pm}$ decays

$M(D_{s1}) = 2535.3^{+0.44}_{-0.41}(stat.)^{+0.09}_{-0.08}(syst.)\ MeV$

$H(D_{s1}) = -0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.)$ (Prel.)

$\Delta M^{ext} = M(K\pi K^\pm) - M(K\pi)$

$p_t(D^0) > 2.80 GeV, \quad |\eta(D^0)| < 1.6$

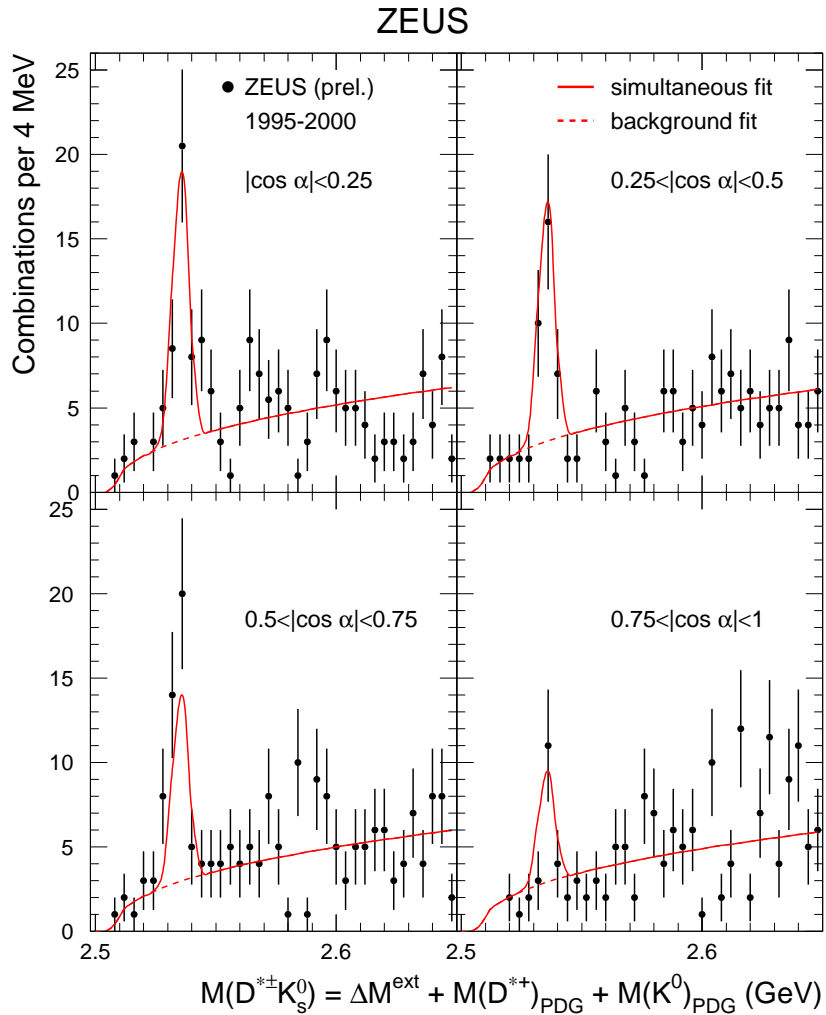$R(\frac{D_{s1}^+ \rightarrow D^{*+}K^0}{D^{*+}}), \quad R(\frac{D_{s1}^+ \rightarrow D^{*0}K^+}{D^0})$

Extrapolated to full kinematic phase space yields:

$\frac{B(D_{s1}^+ \rightarrow D^{*0}K^+)}{B(D_{s1}^+ \rightarrow D^{*+}K^0)} = 2.2 \pm 0.6(stat.)^{+0.4}_{-0.5}(syst.) \pm 0.1(ext.)$ 1.27 ± 0.21 (PDG06)

Excited Charm Strange Mesons 4 Helicity regions

Simultaneous fit of $M(D^{*\pm}K_s^0), M(D^0K^\pm)$ and $cos(\alpha)$ distributions
Gaussian ($Gauss^{mod}$ for $M(D^0K^\pm)$)+ background unbinned liklihood fit

ZEUS

Since $\frac{dN}{dcos\theta} \sim 1 + Hcos^2\alpha$ and H
for $D_{s1}^\pm$ is -0.74,the lower right bin has fewer
events, compared with the D_1^0 case where
H is 5.9,and so this bin had the most events

Summary : Excited Charm Mesons (Prelim.)

	$f(c \to D_1^0)(\%)$	$f(c \to D_2^{*0})(\%)$	$f(c \to D_{s1}^{\pm})(\%)$
ZEUS	$3.5 \pm 0.4^{+0.4}_{-0.6} \pm 0.2$	$3.8 \pm 0.7 \pm 0.6 \pm 0.2$	$1.1 \pm 0.2 \pm 0.1$
CLEO	1.8 ± 0.3	1.9 ± 0.3	
OPAL	2.1 ± 0.8	5.2 ± 2.6	$1.6 \pm 0.4 \pm 0.3$
ALEPH			$0.94 \pm 0.22 \pm 0.07$

CLEO measured smaller resonance widths, OPAL used PDG values

CLEO and OPAL used non relativistic Breit Wigner functions in their fits

Helicity Parameter, H ($D_{s1}^{\pm}$)

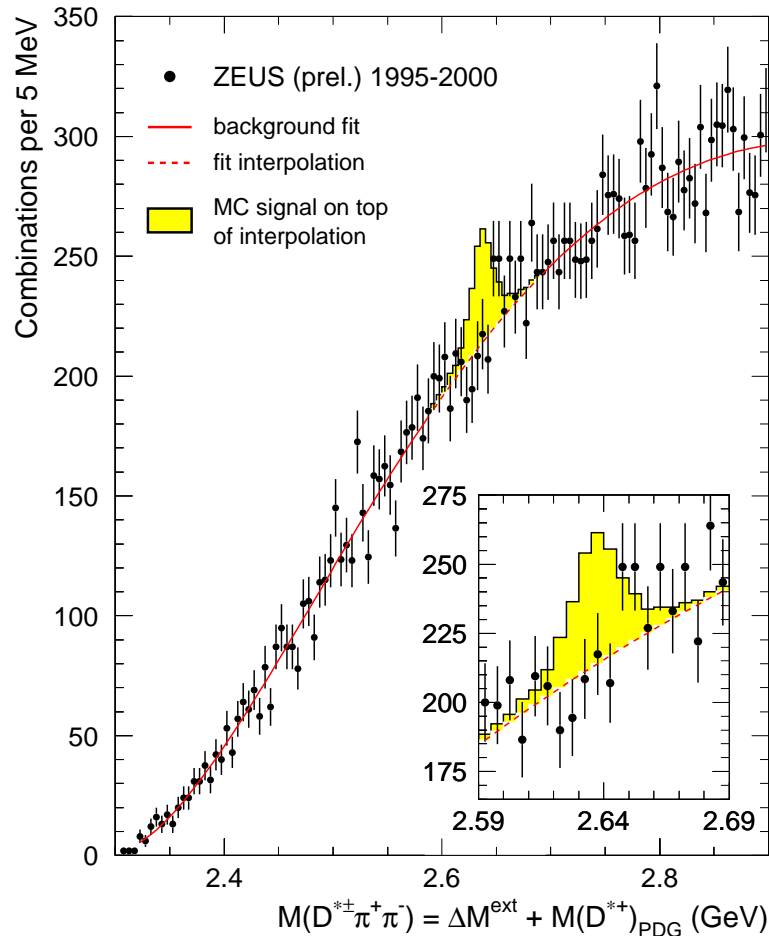|	
ZEUS	$-0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.)$ (Prel.)
CLEO	$-0.23^{+0.40}_{-0.32}$
Belle(prelim.)	-0.70 ± 0.03

$H = 0 \Rightarrow J^P = 1^+$ (if pure S wave), $H = -1 \Rightarrow J^P = 1^-$ or 2^+

Possible (S,D) wave mixing of $D_{s1}^{\pm}(2536)$ with $D_{sj}^{\pm}(2460)$ if both are $J^P = 1^+$

Search for $D^{*'\pm} \to D^{*\pm}\pi\pi$ at $\sim 2.64 GeV$

Combinations per 5 MeV

ZEUS (prel.) 1995-2000

background fit

fit interpolation

MC signal on top of interpolation

$M(D^{*\pm}\pi^+\pi^-) = \Delta M^{ext} + M(D^{*+})_{PDG}$ (GeV)

We searched for (radially excited) $D^{*'} \to D^*\pi\pi$ state

Reported by the Delphi Collaboration , Phys. Lett.B 426,231(1998)
No such state was seen. Our limit for

$f(c \to D^{*'}) \times BR(D^{*'\pm} \to D^{*\pm}\pi\pi)$ is $< 0.4\%(95\%cl)$

This limit is stronger than the 0.9 % OPAL limit (2001)

The inset shows the $D^{*'\pm}$ signal expected for the Delphi value

Summary

- ZEUS:Measured $f(c \to D_1^0), f(c \to D_2^{*0}), f(c \to D_{s1}^{\pm})$
  Our measured rates agree with those of other experiments

- The D_1^0 Helicity $5.9^{+3.0}_{-1.7}$ agrees with H=3,pure d-wave $J^P = 1^+$

- The $D_{s1}^{\pm}$ Helicity Parameter -0.74 $^{+0.23}_{-0.17}$ disagrees with a Pure $J^P = 1^+$, S wave, $D_{s1}^{\pm}(2536)$ state , for which H = 0
  It may be mixed with a $J^P = 1^+$ $D_{sj}^{\pm}(2460)$ state

- We find $\Gamma(D_1^0) = 51.6 \pm 7$ MeV , compared with PDG 06 :
  20.4 ± 1.7 MeV

- Possible explanation : a larger S-wave admixture in ZEUS with a wide resonance , not so in other restricted phase space experiments

- No $D^{*\prime\pm} \to D^{*\pm}\pi\pi$ at ~ 2.64 GeV was seen. New limit set

Backup: Decay of D_1^0, D_2^{*0}

D_1^0 : unnatural parity 1^+ ; cant decay to $0^- + 0^-$ ($D^{\pm}\pi^{\mp}$)

But D_1^0 CAN decay to a p-wave $D^*(1^-)$ plus $\pi(0^-)$

D_2^0 : natural parity, 2^+ so CAN decay to $0^- + 0^-$ (d orbital)

D_2^0 : also can decay to $D^*(1^-)$ plus $\pi(0^-)$, d orbital

Hence D_2^0 was searched both in $D^*\pi$ and in $D^{\pm}\pi$

Relativistic Breit-Wigner was used to describe the resonances:

$$F(m) = C_R\left(\frac{M_R\Gamma_R}{(M_R^2-m^2)^2+M_R^2\Gamma_R^2}\right)$$

Ref: J.D.Jackson, Nuov.Cim. 34,(1964) 1644

Backup: References

ZEUS Collaboration; S. Chekanov et al.

Measurement of K_s^0, $\Lambda, \overline{\Lambda}$ Production at HERA

European Physical Journal C 51 (2007) 1-23

ZEUS Collaboration; S. Chekanov et al.

Measurement of (anti)deuteron and (anti)proton production in DIS at HERA

DESY-07-070 (May 2007),accepted by Nuclear Physics B

ZEUS Collaboration; S. Chekanov et al.

Evidence for a narrow baryonic state decaying to $K_s^0\overline{p}$ in deep inelastic scattering at HERA

Physics Letters B 591 (2004) 7-22

ZEUS Collaboration; S. Chekanov et al.

Search for a narrow charmed baryonic state decaying to $D^{*+}\overline{p}$ in ep collisions at HERA

European Physical Journal C 38 (2004) 29-41

H1 Collab., A. Aktas et al., hep-ex/0704.3594, To be submitted to Phys. Lett. B ,04/07

Search for Baryonic Resonances Decaying to $\Xi\pi$ in Deep-Inelastic Scattering at HERA

H1 Collab., A. Aktas et al., Phys. Lett. B 639 (2006) 202

Search for a Narrow Baryonic Resonance Decaying to $K_s^0 p$ or $K_s^0 \overline{p}$ in Deep Inelastic Scattering at HERA

H1 Collab., A. Aktas et al., Eur. Phys. J. C36 (2004) 413-423

Measurement of Anti-Deuteron Production and a Search for Heavy Stable Charged Particles at HERA

H1 Collab., C. Adloff et al., Z. Phys. C76 (1997) 213

Photoproduction of K^0 and Λ at HERA and a Comparison with Deep Inelastic Scattering

Backup: References

CLEO Coll., P. Avery et al.,Phys. Lett. B 331, 236 (1994)

OPAL Coll., K. Ackerstaff et al.,Z. Phys. C 76, 425 (1997)

ALEPH Coll., A. Heister et al.,Phys. Lett. B 526, 34 (2002)

CLEO Coll., J.P. Alexander et al.,Phys. Lett. B 303, 337 (1993)

BELLE Coll., K. Abe et al.,(hep-ex/0507030)

CDF Coll., A. Abulencia et al.,Phys. Rev. D 75,32003 (2007)